DISTRIBUTION AND SEDIMENTS OF MANGROVE FORESTS IN SOUTH AUSTRALIA

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Summary

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A survey of forests of the mangrove *Avicennia marina* in South Australia was conducted in summer, 1974-75. This paper describes the distribution of the forests and contains detailed maps of the major stands. Smear slides of the sediments have been examined and on this basis two geographically distinct types are identified. The dynamic relationship between the sediments and the organisms growing within them is discussed. Extinct mangrove swamps at three sites are described and the past distribution of mangroves is discussed. Finally we comment on the composition of the communities of organisms in South Australian mangrove swamps.

Introduction

Mangrove forests are most complex and luxuriant in the wet tropics of the Indo-West-Pacific region (Macnae 1968), but extend onto desert shores and to latitudes at high as that of Westernport Bay, Victoria (38°22′). South of the Queensland/New South Wales border there are only two species of mangroves, *Avicennia marina* and *Aegiceras corniculatum*, and south of Sydney there is only *Avicennia marina* (Forst.) Vierh. (Macnae 1966). The stands of this species at Westernport Bay, Victoria, are the southern-most mangroves in the world.

In South Australia, the flora and fauna of mangroves are briefly mentioned by Womersley & Edmonds (1958). Wester (1967)[1] surveyed the distribution of mangroves throughout South Australia using both aerial photographs and inspections on the ground. There is evidence that the South Australian mangroves have been more extensive than they are today; Cotton (1949) reported the exposure of an old mangrove mud-flat under the sand of the beach at Glenelg and he suggested that mangroves lived "until a comparatively short time ago" as far south as Port Noarlunga.

It has frequently been argued that South Australian mangrove forests are important communities in a number of ways, for example in the support of fisheries and the stabilization of sediments, and for these and other reasons steps have been taken to conserve them.[2] Whilst it is clear that mangroves in various places in the world have such functions it is now obvious that "mangrove forests" occur in widely varying conditions and vary considerably in their composition and functioning (Davis 1940, Thom 1967, Bird 1971, Carlton 1974, Lugo & Snedaker 1974, Walsh *et al.* 1975[3]). Thus it is desirable to obtain information, in South Australia, about the dynamics of mangrove ecosystems here.

This paper is merely a preliminary step towards such knowledge. It is based on a survey[2] with the following aims: to check the distribution of mangroves in South Australia and

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[1] Wester, L. L. (1967).—The distribution of the mangrove in South Australia. B.A. (Hons.) thesis, University of Adelaide. Unpublished.

[2] Butler, A. J., Depers, A. M., McKillup, S. C. & Thomas, D. P. (1975).—The Conservation of Mangrove Swamps in South Australia. Report to the Nature Conservation Society of S.A.

[3] Walsh, G. E., Snedaker, S. C. & Teas, H. J. (1975) (Eds).—Proceedings of the International Symposium on Biology and Management of Mangroves, Honolulu, October 1974. (Institute of Food and Agricultural Sciences, University of Florida, Gainesville.)

to record as well as possible their biota, the nature of the sediments in which they grow, the condition of each forest in terms such as the health of the trees and whether the sediment be accreting or eroding, the types of communities to landward and seaward, and human activities in and near mangrove forests. In general, it was beyond the scope of the project to seek explanations for our observations. This paper records the distribution of mangrove forests in South Australia at that time, observations on the sediments, notes on past distribution and brief comments on the composition of mangrove communities. More detailed biological and general notes will be published elsewhere.

Methods

During the summer of 1974–75 almost all stands of mangroves in the State were visited at least once; selected areas were re-visited for more detailed inspection. On these trips we were guided by copies of Wester's[1] maps, and aerial photographs[4] of most of the mangrove stands.

In addition to stands recorded by Wester, we visited several areas where they might have been anticipated to occur. For each location, map accuracy was checked against the 1972 aerial photographs and also by ground surveys. Notes were made of human activities, and of the types of habitats lying to landward and to seaward of the mangroves. Special note was taken of the health and size distributions of the trees, the extent of leaf-damage, and apparent sedimentary processes at each area.

Sediment samples were collected and stored in polyethylene containers. Preliminary tests for carbonate content were made in the field using dilute hydrochloric acid. In the laboratory, smears of the samples were mounted on microscope slides in Caedex resin and examined by transmitted light at a maximum of 400X magnification. Surface scrapes and the sediment smears were examined for the presence of microflora (diatoms, blue-green algae, other algae), and collections of animals were taken at each site.

Observations and Discussion

DISTRIBUTION

Stands of *Avicennia marina* occur at the locations shown in Figure 1. All are in sheltered sites as noted by Womersley & Edmonds (1958). The most extensive stands (Figs 2–8) are near Ceduna on north western Eyre Peninsula, at Franklin Harbour on Spencer Gulf, around the heads of both Gulfs, and near both Port Pirie and Port Adelaide.[5] We found no evidence to extend the past distribution of mangroves any further south than the stand at Glenelg reported by Cotton (1949).

SEDIMENTS

Generally the South Australian mangroves grow in carbonate-rich sediments, but the percentage carbonate varies considerably, both within and between mangrove communities.

In a mangrove community the seaward side is flanked by extensive intertidal shell-grit sands with or without seagrasses (e.g. *Heterozostera* or *Posidonia*) whilst to landward the mangroves are flanked by samphires and occasionally by extensive supratidal lagoons. Beach ridges of shell-grit and dead *Posidonia* are commonly found here, marking the position of a previous coastline, prior to large sea-level changes.

Sediment types

The mangrove sediments were classified according to depositional texture using Dunham's (1962) classification.

Two different types of mangrove sediments could be distinguished on the basis of grain-size. One, a wackestone-packstone-boundstone, is confined to Eyre Peninsula; the second, a boundstone, is found in northern and eastern Spencer Gulf and Gulf St Vincent.

(1) The wackestone - packstone - boundstone type of sediment was found in all the areas on Eyre Peninsula, from south of Whyalla to Davenport Creek. We shall refer to this as the "West Coast" type. It generally has particles in the clay to medium sand size category (Folk 1974, p. 25). Boundstone sediments are usually found within the mangroves away from tidal channels and creeks. They are covered by a mat of blue-green algae that binds the top 2–5 cm of sediment together. Laminae of such algae can be found in long-established sediments. The boundstone consists dominantly of clay to silt sized particles. The wackestone-packstone sediments are usually found closer to the main tidal channels where coarser particles of silt to sand size are introduced during the tides.

[4] The aerial photographs were taken by the Department of Lands, S. Aust., in November 1972, for the Fisheries Department, S. Aust., which now holds them.

[5] Maps of all mangrove stands are presented in Butler et al. (1975)[2].

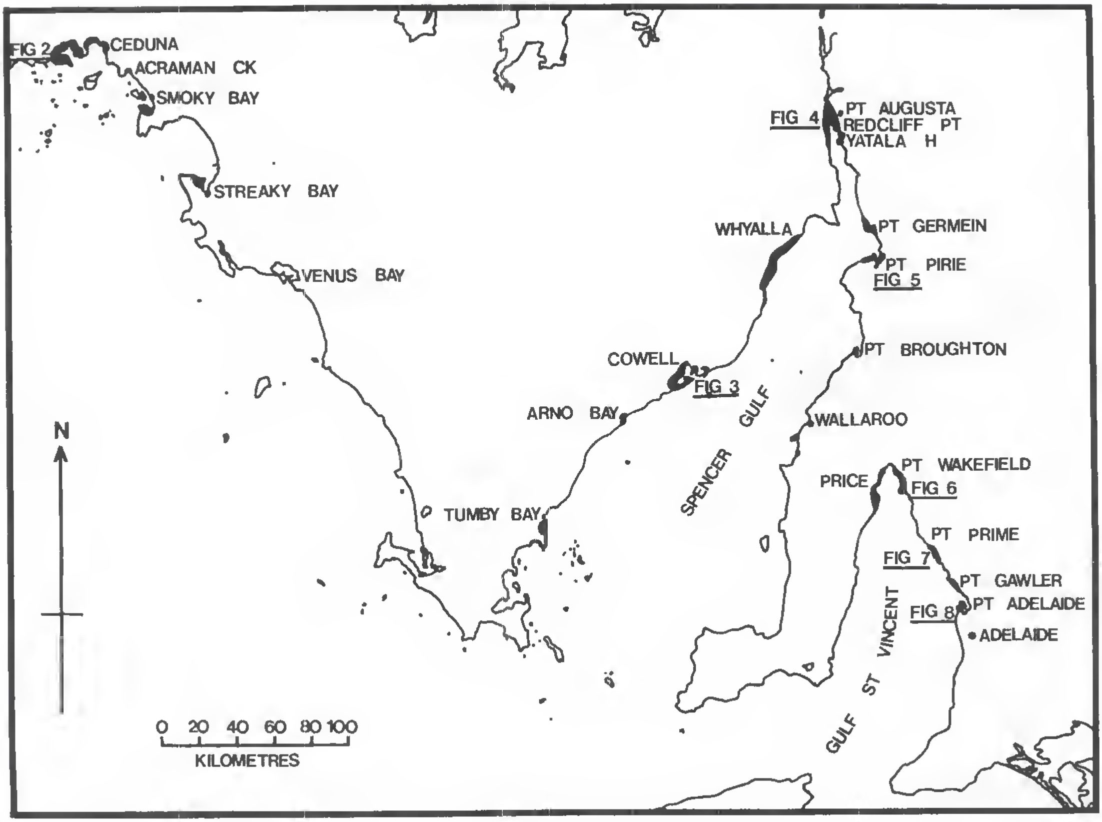

Fig. 1. Distribution of stands of *Avicennia marina* in South Australia, showing locations of stands mapped in Figs 2–8.

They contain a lower percentage of clay sized particles, partly attributable to the winnowing effect of the tides; the tidal waters suspend the the fine material and whilst in suspension it is carried to the backwaters of the mangrove community where it is deposited.

The "West Coast" sediments consist dominantly of quartz, carbonate clay, algal and shell fragments, foraminifera and diatoms. Most of the quartz is rounded to sub-rounded, with some particles subangular (Powers 1953). The percentage of organic carbon, mainly decomposing mangrove and seagrass leaves, varies greatly with location within a given mangrove community, with depth in the sediment and between communities. Minor constituents are echinoid spines, aragonite rosettes and needles, sponge spicules (silica), radiolarian tests (opaline silica) and minerals from the hinterland (e.g. amphiboles and feldspars).

Due to the low-energy depositional environment in which these sediments are found, it is deduced that the quartz is introduced from the extensive beaches and sand-dunes in or near the mangrove stands. These are, or were, environments of much higher energy. The quartz-grains are introduced into the mangrove community either by long-shore drift in the beach environment and then via tidal water, or else by saltation from the surrounding sand-dunes.

Other constituents in the sediments find their way into the mangrove communities via tidal channels, or live and die on the sediments and hence are incorporated (e.g. diatoms).

(2) The boundstone sediments found in Spencer Gulf north and east of Whyalla and in Gulf St Vincent, will be referred to as the "Gulf" type. The particles are predominantly of clay to fine silt size, although there is local variability. These sediments too are covered by an algal mat. The major constituents are similar to those of the "West Coast" sediments. However, the quartz grains are rounded to subrounded and clear, whereas in "West Coast" sediments they usually have rutile and tourmaline needle inclusions. Some minor constituents, especially radiolarian tests and sponge spicules,

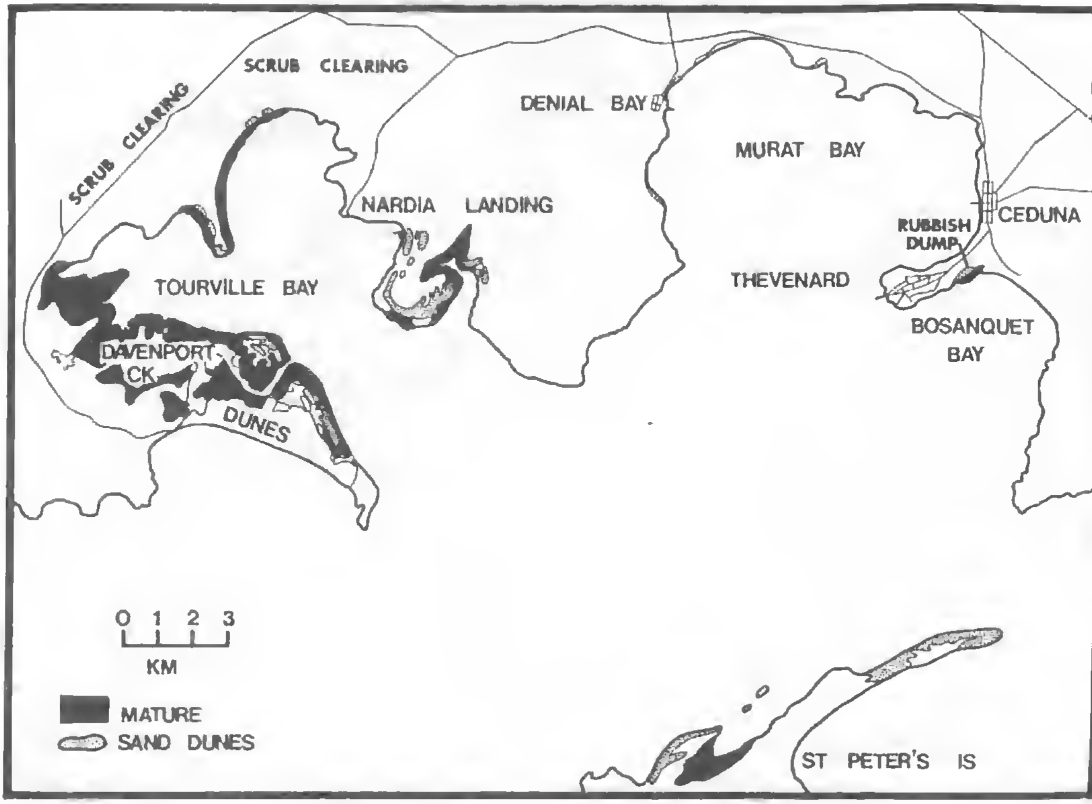

Fig. 2. Davenport Creek, on the west coast.

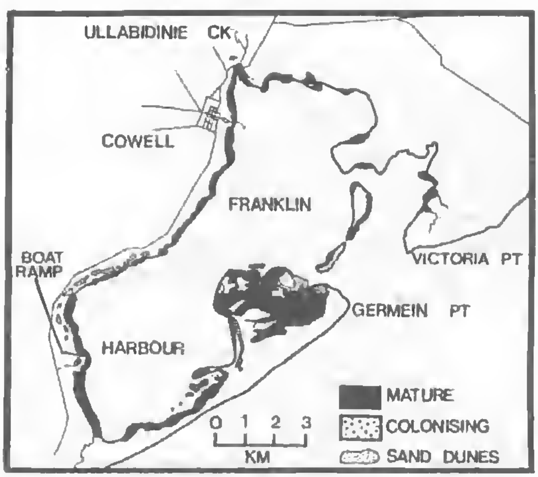

Fig. 3. Franklin Harbour, Spencer Gulf.

are absent. The lack of minerals such as amphiboles and feldspars, like the lack of inclusions in quartz grains, results from the absence of significant metamorphic rock sources in the hinterland of the "Gulf" areas. By comparison, the hinterland of the "West Coast" areas contains a variety of metamorphic sources (Glaessner & Parkin 1958).

Areas studied in more detail

(1) At Port Gawler in Gulf St Vincent (Fig. 7), very rapid sedimentation, with a consequent relative drop in sea-level, has left a very thick pile of sediment in which the present well-established mangroves grow. Deep tidal channels supply the area with seawater. Near the present beach a new mangrove colony has become established, and from a series of aerial photographs it is clear that the lower-tide region of the beach has been progressively colonized within the last 10 years.

Statistics from the smear slide results (Table 1) show certain trends from colonizing mangroves to mature stands. Generally, quartz content decreases as does the grain size of quartz (from medium sand size to fine silt size), carbonate clay increases, the contents of algal and shell fragments decrease along with their grain size (medium sand size to medium silt size), and organic carbon increases. Clearly the trends are not statistically significant in several cases, because of wide variability. However, it was

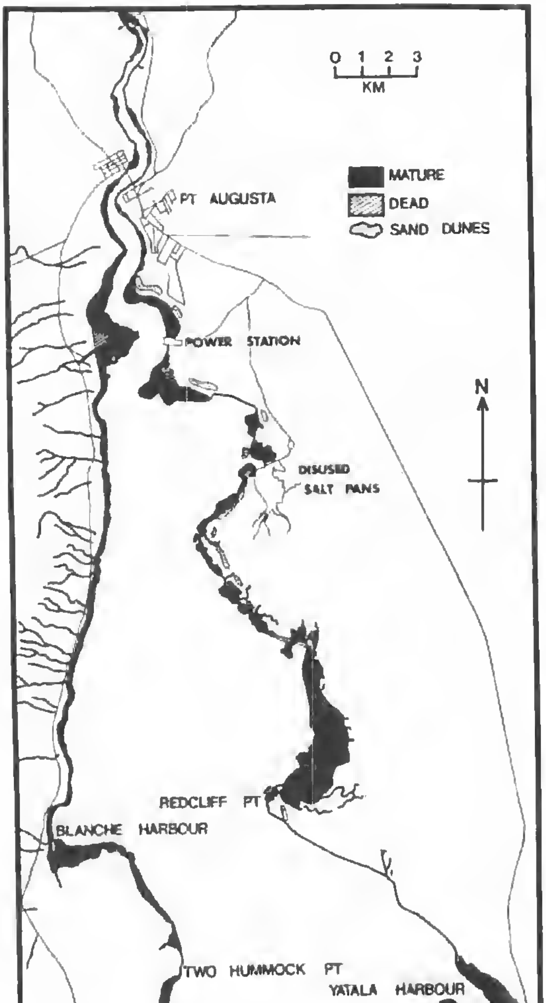

Fig. 4. Northern Spencer Gulf.

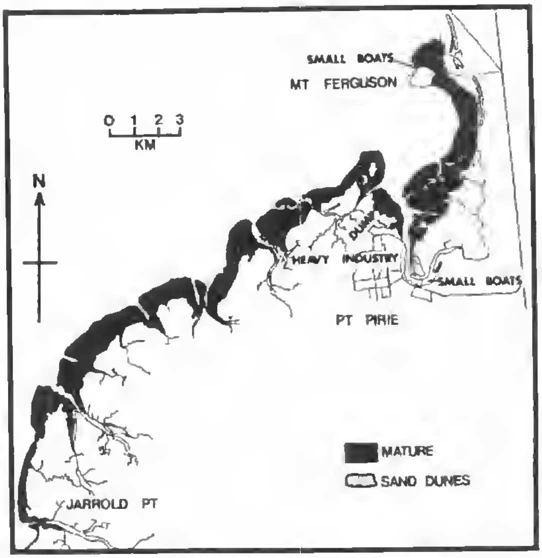

Fig. 5. Port Pirie, Spencer Gulf.

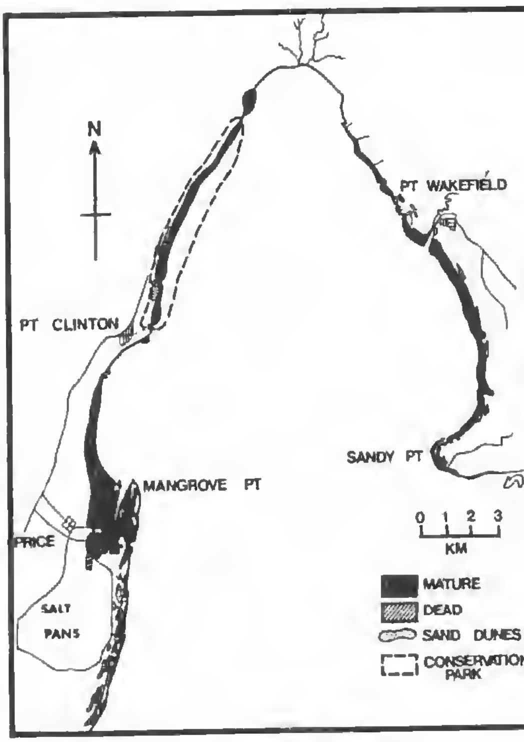

Fig. 6. Northern Gulf St Vincent.

not possible to obtain more data and it seems unwarranted to carry out a more complete statistical analysis of these data. The apparent trends suggest that as mangroves begin to colonize, usually in a shell-grit grainstone of fine sand size, the stabilizing effect of the trees and pneumatophores allows sedimentation of much smaller particles to commence. The final result is an algal-covered fine-grained sediment. The depositional texture of the sediments changes from grainstone to wackestone-packstone then to boundstone. A major factor in these changes would appear to be the activity of species of the blue green alga *Oscillatoria* and the golden brown alga *Vaucheria*.

All of the mangrove sediments are underlain by a coarse grainstone composed of shell fragments from gastropods, bivalves and forams. The influence of this layer is not known, but we suggest that it is important in the growth of the mangroves. Being a coarse

TABLE 1

Statistics from examination of smear slides of sediments from S.A. mangroves

PORT GAWLER

Type of colony	No. of samples		Quartz	Clay	Algal + shell fragments	Forams	Aragonite	Org C	Diatoms	Others
Juveniles up to 50 cm high	10	Mean	37.00	14.90	42.30	1.50	0.20	2.70	1.40	0.00
		S.D.	8.13	7.59	11.18	0.71	0.42	3.05	1.43	0.00
Saplings up to 2 m high	5	Mean	37.00	8.60	45.60	4.00	2.00	2.01	0.80	0.00
		S.D.	13.51	9.24	2.88	3.67	1.73	2.73	0.84	0.00
Mature trees 2 m and more	12	Mean	30.00	28.33	24.58	1.27	0.42	13.75	2.09	0.00
		S.D.	13.98	18.56	13.65	0.37	0.66	9.32	2.02	0.00

DAVENPORT CREEK-CEDUNA

Type of colony	No. of samples		Quartz	Clay	Algal + shell fragments	Forams	Aragonite	Org C	Diatoms	Others
Juveniles up to 50 cm	2	Mean	5.00	27.50	59.00	1.00	0.51	3.50	3.50	0.00
		S.D.	0.00	3.54	2.83	0.00	0.70	2.12	2.12	0.00
Trees 2 m and more	27	Mean	25.00	22.74	34.45	1.82	1.12	12.22	1.78	1.30
		S.D.	22.63	15.67	27.46	1.84	1.74	12.92	1.88	2.30

layer it is also very porous and permeable, so that seawater can move through it freely. This may be important in the functioning of the soil ecosystem and in the nutrient-balance of the trees.

Within the mangrove stands deep burrowing by the crab *Helograpsus haswellianus* (Whitelegge) and other organisms, especially various polychaete worms, bioturbate the sediment extensively. The result is that the algal laminations are destroyed and a mottled texture is commonly found in cross-sections of the sediment. Through these crab holes the water is able to permeate.

(2) In the Davenport Creek area near Ceduna (Fig. 2) extensive, mobile, carbonate-rich sand-dunes are present. These are very coarse-grained (medium sand to coarse sand size) and are composed of about 95% shell fragments and 5% rounded to sub-rounded medium sand size quartz. The prevailing southwesterly wind blows the dunes directly onto the mangrove community to the north-east of the beach, and the mangroves are gradually dying near the sand-dunes due to the "blanketing" movement of the dunes. Not far from its mouth the tidal channel called "Davenport Creek" has cut through the highly organic mud of a former mangrove forest which appears to have been killed by saltation with marine sand.

The mangrove sediments from Davenport Creek are rich in carbonate and quartz (Table 1). Except for the variation in organic carbon the changes from colonizing to mature stands are less clear, but we assume that a process like that described in (1) above occurs here. The sediments here are much coarser-grained than at Port Gawler, and again a coarse grainstone underlies the mangrove sediments.

In the tidal channels, extensive burrowing by polychaete worms has left a mound-covered terrace, not seen in any of the other areas studied, but the crab *Helograpsus* is rare; this seems to be general for "West Coast" sediments.

Within the mangroves are to be found a series of stranded beach ridges (probably cheniers). Since these represent previous shorelines (the ridges are built up during storms and contain extensive beds of dead *Posidonia* sp.) we infer that this area has been subjected to a number of sea-level changes. There are three such ridges visible and probably several more buried under the dunes. They are grainstones composed of coarse gastropod-bivalve-shell fragments, now overlain by a soil profile supporting small bushes and grasses. Similar stranded beach ridges are found in the other mangrove areas (e.g. Yatala Harbour, Port Pirie, Port Gawler).

(3) Yatala Harbour, south of Red Cliff Point in Spencer Gulf (Fig. 4) was studied in detail prior to this survey.[6] This area exemplifies the "Gulf" type of sediment described above.

[6] Depers, A. M. (1974).—Sedimentary facies at Yatala Harbour and a geochemical comparison with Port Pirie sediments, Spencer Gulf, S.A. B.Sc. (Hons.) thesis, University of Adelaide. Unpublished.

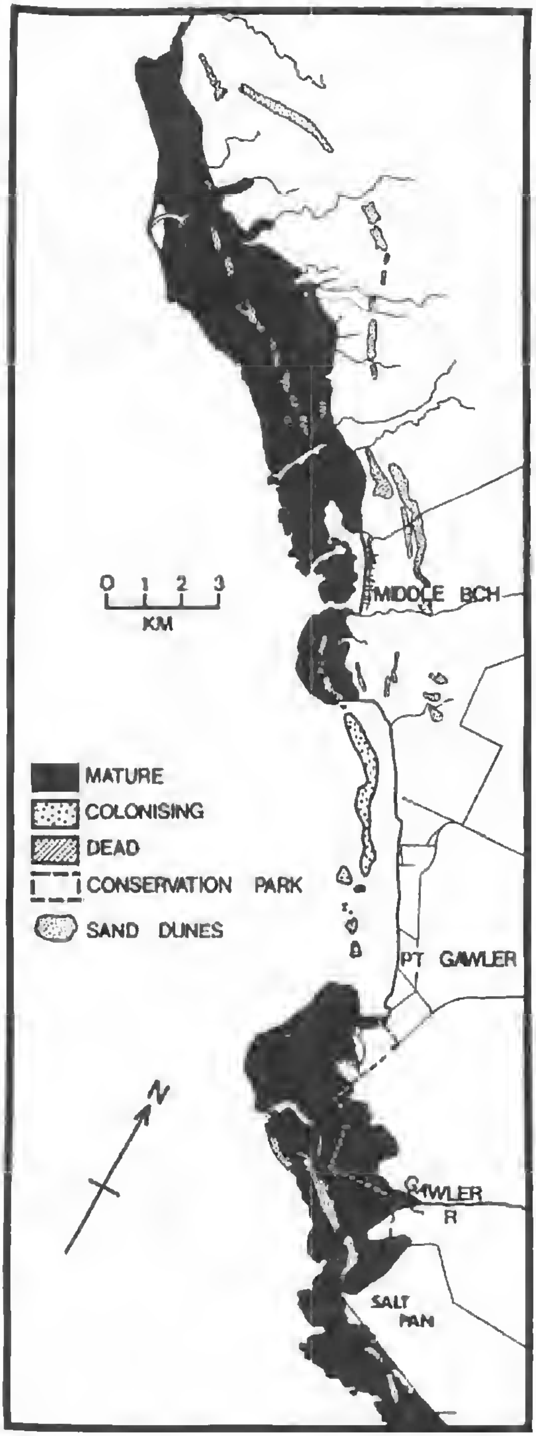

Fig. 7. Middle Beach and Port Gawler, Gulf St Vincent.

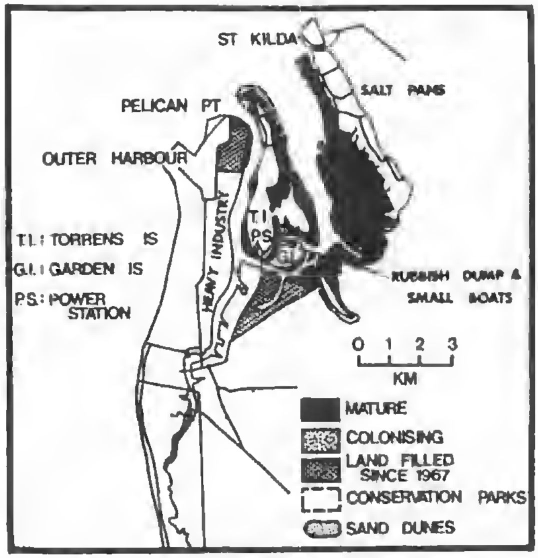

Fig. 8. Port Adelaide, Gulf St Vincent.

A thin sequence of Holocene sediments occurs in a prograding carbonate shoreline. To seaward, the area is flanked by shell-grit grainstones and *Heterozostera* seagrass banks; in deeper water are banks of *Posidonia* seagrass. On the landward side are extensive supratidal carbonate lagoons and samphires.

The mangroves grow in grey sediments consisting of from 60% to 100% carbonate mud as estimated by areas on smear slides. Terrigenous clay can be as high as 35% and organic matter up to 20%. Smear slides of the sediments show that the carbonate is dominantly precipitated calcite rhombs (45–87%) with minor aragonite rosettes ($\leqslant$1%) and some dolomite rhombs ($\leqslant$1%). The remainder of the carbonate fraction (6–30%) consists of mainly algal fragments and smaller amounts of foraminifera, echinoid spines and bryozoan fragments. Most of the particles are clay to medium silt sized. Quartz grains are generally rounded to sub-rounded, with the occasional angular grain present. Similar sediments have also been found at Port Pirie.

The algal mats which grow on bare mud and hold the surface sediments together are partially laminated in section. Subaerial exposure causes them to crack and curl. The mud crab *Helograpsus* plays an important role in bioturbating the sediment. The tidal channels are large and usually contain water at low tide. Some of the channels are very rich in decaying organic matter, especially masses of dead leaves of *Posidonia* sp., and smell strongly of hydrogen sulphide. In one channel, 12 cm of solid

black peat was found. The tidal channels commonly contain a channel-lag wackestone, consisting of a concentration of bivalve and gastropod shells.

Extinct Mangrove Stands

Extinct mangrove stands have been recorded at Glenelg (Cotton 1949), at Webb Beach near Parham, and at Davenport Creek (above). We examined only one, Baker's Creek at Webb Beach, in any detail. Here we found two well-preserved platforms of sediment bound by algal mats, one overlying the other with about 15 cm of shell fragment grainstone between them.

Dead tree stumps lie within the platforms. Smear slides showed that the sediments are similar in composition to those found in other areas. Both are carbonate-rich; they are extremely rich in organic carbon, and this is true of all the extinct stands we have seen. Probably the algal layer protects the sediment and, because it does not break apart, decomposition is extremely slow.

There is some evidence of considerable sea-level changes in this area (S. Carr, pers. comm.; Ward & Jessup 1965) and the presence of two mud platforms one above the other may also indicate such changes. But the evidence from the extinct mangrove platforms is not conclusive, because mangroves can live over a range of altitudes in the intertidal zone (Butler unpubl.).

To the south of the extinct stand is a small stand of living mangroves in a tidal channel relatively protected from the dominant sea swell.

The deaths of the two Webb Beach stands seem likely to be the result of encroachment of shell-grit facies over the mangrove boundstone. Extensive dunes on the landward side also could have had an effect on the mangroves.

Sedimentary Dynamics—Conclusion

Within the mangrove community, a dynamic relationship exists between the sediment and the plants growing in and on it. Some sediment must be present for colonization by the plants, but once they have colonized rootlets, pneumatophores and algal mats stabilize the sediment; algal mats facilitate the entrapment and precipitation of carbonate grains (Bathurst 1971; Carlton 1974; Gebelein 1969; Neumann et al. 1970; Scoffin 1970). This relationship is a delicate one, as each supports the other.

It is clear that the persistence of a mangrove forest depends greatly on sedimentary processes. There are places (e.g. Port Clinton) where erosion of the sediment is leaving the trees without support and they are dying without replacement. In others (e.g. part of Davenport Creek) saltation or encroachment by dunes is killing the forests; it appears that in some such cases mature trees survive but seedlings cannot establish, so that the forest eventually disappears. We cannot cite clear cases of the opposite, where death of mangroves results in erosion of the sediment, but it is possible.

EXTINCT MANGROVE FORESTS, AND NOTES ON HISTORY

We have found sheets of mangrove mud containing dead stumps at Davenport Creek, west of Ceduna, and at Webb Beach, Gulf St Vincent. Cotton (1949) reported such a mudflat briefly exposed at Glenelg, and suggested "from faunal studies" that mangroves existed "until a comparatively short time ago" as far south as Port Noarlunga.

Cotton postulated that mangroves are gradually retreating northwards in Gulf St Vincent. Independently of that, he also suggested because some of the mollusc shells in the mud were larger than present-day specimens that when the forest at Glenelg flourished conditions were a little warmer than at present. We have found, in conversation, a popular local belief that mangroves are retreating northwards because conditions are becoming cooler, so that they cannot survive further south. We do not think this is the best interpretation of the facts.

The distribution of the known extinct stands is not consistent with a simple retreat up the Gulf. Cotton postulated that the mangrove forest at Glenelg was contemporary with the red sand-dunes which lay behind the recent, white dunes and that it flourished 1000–3000 years ago, finally being killed by "sand-silting".

As noted above, we think that the death or reduction of forests in several areas can be explained in terms of sedimentary processes—encroachment by dunes, saltation or erosion.

It is beyond the scope of this paper to discuss broad patterns of changes in sea level, climate, wind, wave and current patterns and coastal morphology into which these cases might fit, but we think it is clearly not a simple case of mangroves retreating north as the climate cools. That would be inconsistent with the fact that they occur much further south at Westernport Bay, Victoria. Rather, we see mangroves as living in very dynamic sediments with

siltation, saltation and erosion taking place in different stands according to the local conditions at this time.

We have also encountered a "popular belief" that mangroves were much more extensive in South Australia on the arrival of white settlers than they are now, for example, that they occupied the beach at Glenelg and occurred at Port Noarlunga. It is said they were cleared because people feared malaria. This belief may be accounted for by a misreading of Cotton's (1949) paper, by a misidentification of the plants, or by its being true. We decided to find what we could from the writings of early settlers.

Cotton (1949) noted that "a sketch of [the Glenelg] area by Colonel Light in about 1835 depicts the beach pretty well as at present". Light (1839; also quoted by Bull 1884) gave a bearing and latitude which clearly placed him off Outer Harbour when he noted "to the northward and eastward mangroves growing to the water's edge". These must have been the mangroves of Torrens Island, St Kilda and northwards to Port Gawler. At another time sailing northward along Holdfast Bay he recorded "hard sandy beach the whole way".

Certainly extensive areas of tidal swamps in the Port Adelaide region and to the south have been filled.[7] Much of this has been done within recent memory, but the beach at Glenelg was not created in this way; the mangroves there appear to have been buried more than 130 years ago. We cannot be sure about Port Noarlunga.

COMMUNITIES OF ORGANISMS IN S.A. MANGROVE SWAMPS

Lists of flora and fauna collected will be presented elsewhere but the following remarks based on those lists are worth recording here.

We found no trends across the State that would be interesting biogeographically; rather, any of the species could be expected if conditions were appropriate. This is not surprising, as all the mangrove forests fall within the Flindersian Province defined by Womersley & Edmonds (1958). By definition, *Avicennia* was always present; most commonly there was an extensive saltmarsh to landward, dominated by *Salicornia* or with *Salicornia* and *Arthrocnemum* codominant, and bare mud flats or seagrass beds usually lay to seaward of the mangroves. The fauna varied between sites.

It does not appear that there is a unique assemblage of organisms which might be called a "typical South Australian mangrove community", i.e. an assemblage of species which nearly always occur together. Even the animal species most commonly associated with mangroves, such as the crab *Helograpsus haswellianus* and the snail *Bembicium auratum*, are sometimes rare or absent, and they do occur commonly in the absence of mangroves.

These observations indicate that the distribution and abundance of species in the tidal swamps depends primarily on the requirements of the individual species, and on factors such as substrate type and height of sediment above mean sea level, rather than on the presence of the mangrove itself. This is in general agreement with the conclusions of Clarke & Hannon (1971) on plant zonation in tidal swamps in the Sydney district, and of Macnae (1968) on the distribution of animals within mangrove forests.

All areas of mangroves in South Australia have features in common, because *Avicennia marina* has certain requirements (Clarke & Hannon 1967, 1969, 1970, 1971; Farrell & Ashton 1974[8]). But the mangrove is flexible in its requirements and in most respects it appears to have wide tolerances. This is reflected in the variable communities of organisms that live with it.

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[7] Mangroves to the south of North Arm, and along creeks south of the docks at Port Adelaide, can be seen in 1935 aerial photographs held by the Geography Dept., University of Adelaide. (RAAF aerial photography: Eden Area (Adelaide Survey) (9-11-35) Frames 03894,5,7,8,9 and 03918, 19,20.) Most of these have been filled; thus they are absent from our Fig. 8. Fig. 8 shows those filled since 1967.

[8] Farrell, M. J. & Ashton, D. H. (1974).—Environmental factors affecting the growth and establishment of mangroves in Westernport Bay (Report to Westernport Bay Environmental Study, Melbourne, November 1974).

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